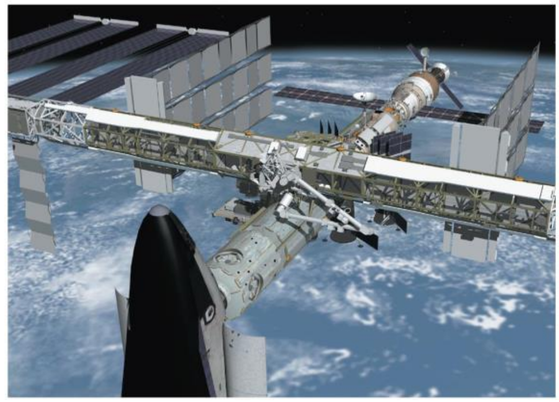
PHY131 F Fall 2020
Class 15

Today:

- The last few slides on Chapter 5 on Circular Motion
- Starting on Chapter 6:
- Momentum
- Conservation of Momentum during collisions



1

Midterm Assessment 2 Marking is still ongoing…

- The TAs have asked for a bit more time to finish marking of the Midterm Assessment 2.
- I plan to talk more about this in Wednesday’s class, by which time the marks should be released.

2

Circular Orbits

An object moving in a circular orbit of radius r at speed v_{orbit} will have centripetal acceleration of

$$\Sigma F_r = \cancel{m}\frac{v^2}{r} = \cancel{m}g$$

$$a_r = \frac{(v_{orbit})^2}{r} = g$$

F_{g_E} on o $= mg$

$$\frac{v^2}{r} = g$$

That is, if an object moves parallel to the surface with the speed

$$v^2 = gr$$

$$v_{orbit} = \sqrt{rg}$$

$$v = \sqrt{gr}$$

then the free-fall acceleration provides exactly the ~~centripetal~~ radial acceleration needed for a circular orbit of radius r.

Near the surface of the Earth, this speed is about 8 km/s.

An object with any other speed will not follow a circular orbit.

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Quick Poll

In a Low Earth Orbit, a satellite is only a few hundred km above the surface. A satellite there can travel around the world once every 90 minutes. The Hubble Space Telescope is one example.
Why don't satellites have orbits that are less than 300 km above Earth's surface?

A. ~~Lower than that they would be subject to Earth's gravitational pull, and the satellite would fall down~~
B. ~~Lower than that they would be too far from the Sun, and could not collect enough solar power~~
C. Lower than that they would be subject to too much air resistance, and would fall or burn up
D. ~~Lower than that they would be subject to too much radio interference on Earth~~
E. Lower than that they would not be able to communicate with the entire Earth at one time

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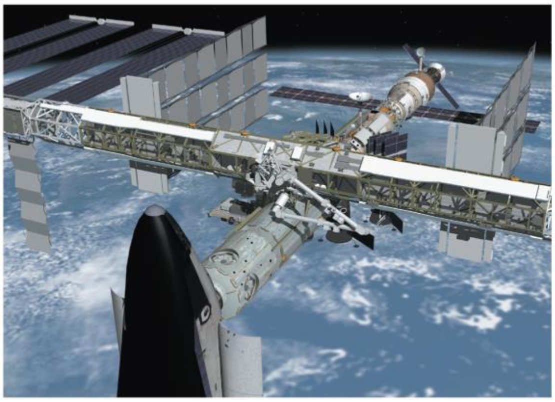
Circular Satellite Orbits



- Positioning: beyond Earth's atmosphere, where air resistance is almost totally absent
- Example: Low-earth orbit communications satellites are launched to altitudes of 300 kilometers or more, in order to be above air drag
- But even the ISS, as shown, experiences *some* air drag, which is compensated for with periodic upward boosts.

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The state of physics around 1650…

- In 1609 Galileo started observing the sky with a telescope.
- Around that same time, Kepler was investigating careful observations of the apparent positions of planets in the sky.
- It was determined that planets orbit the Sun, and that Earth was the third planet out from the Sun.
- Kepler noted that the shapes of the orbits of all the planets were not quite circles, but actually ellipses.

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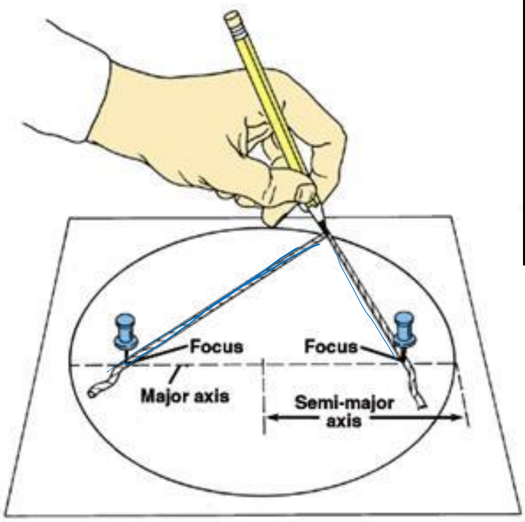
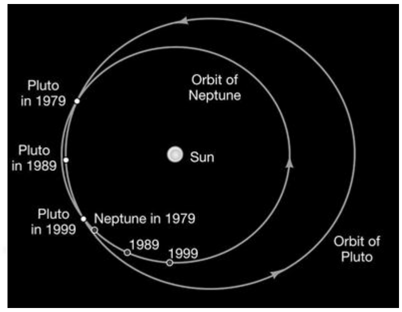
An ellipse is a mathematical shape.





- The furthest distance from the centre of an ellipse to its edge is called the "semi-major axis"
- The eccentricity, e, tells you how squished the orbit is.
- A circle is a special case of an ellipse, when $e = 0$.

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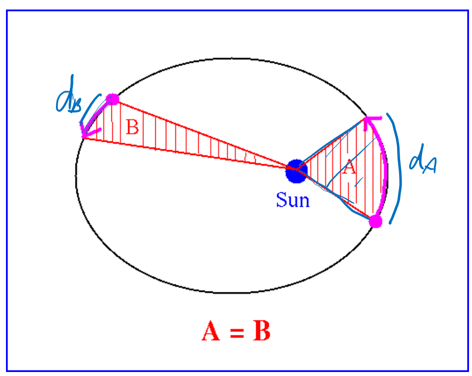
Kepler's Laws of Planetary Motion

1. Planets, asteroids and comets move in orbits whose shapes are ellipses, with the sun at one focus of the ellipse. (Planetary orbits normally have low eccentricity: almost circular.)

2. A line drawn between the sun and a planet sweeps out equal areas during equal intervals of time. (They go faster when they are closer to the sun.)



$d_A > d_B$

$v_A > v_B$

3. The square of a planet's orbital period is proportional to the cube of the semimajor-axis length. ($T^2 = C\, r^3$, where C is some constant.)

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$f_k = \mu_k N$

Newton's Laws

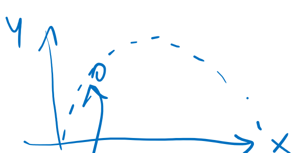
• Kepler's Laws are empirical, like Hooke's Law, or the equation for kinetic friction or drag. They were written down in order to describe the observations. Kepler did not know "why" the planets moved in this way.

• Many scientists at the time, including Edmund Halley, believed that there was some kind of force from the Sun pulling the planets, asteroids and comets toward it.

• In 1687 Isaac Newton published one simple theory which explained all of Kepler's laws, as well as motion observed here on Earth:

- The 3 Newton's Laws you already learned, plus:
- "Newton's Law of Gravity" $F_{grav} = \frac{G m_1 m_2}{r^2}$

Projectile Motion and Orbits

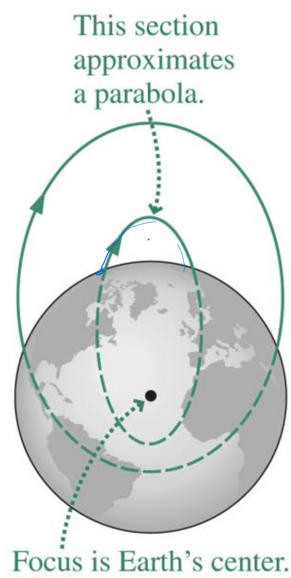


$a_y = -9.8 \, m/s^2$

$a_x = 0$

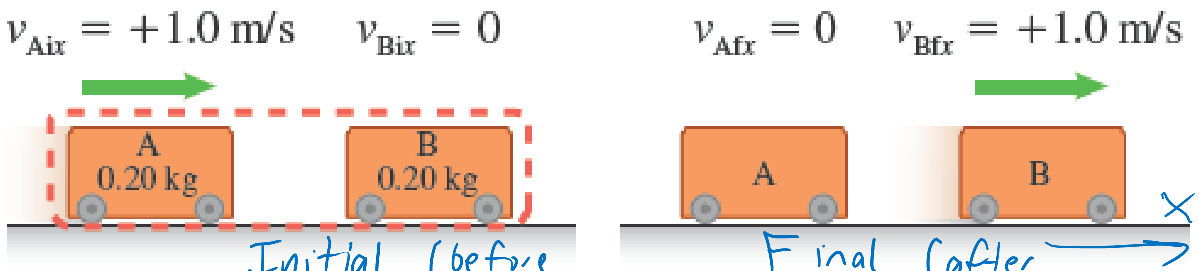
parabolic trajectory

- The "parabolic" trajectories of projectiles near Earth's surface are actually sections of elliptical orbits that intersect Earth.
- The trajectories are parabolic only in the approximation that we can neglect Earth's curvature and the variation in gravity with distance from Earth's center.



Ch.6 Observational Experiment 1

$\boxed{p_x = m v_x}$ "momentum"



Initial (before collision)

Final (after collision) $\rightarrow x$

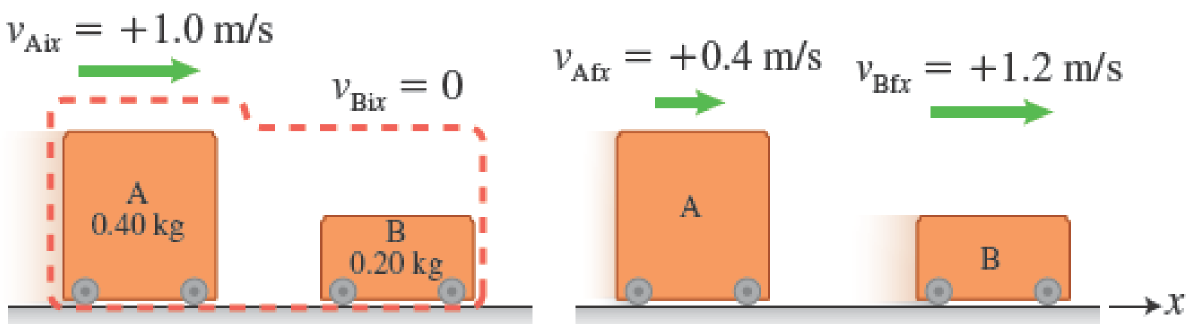
$p_{ix} = 0.2(+1.0) + 0$
$= +0.2$

$p_{fx} = 0 + 0.2(+1.0)$
$= +0.2$

$\boxed{p_{ix} = p_{fx}}$ Hmmm...

Ch.6 Observational Experiment 2

$p_x = m v_x$

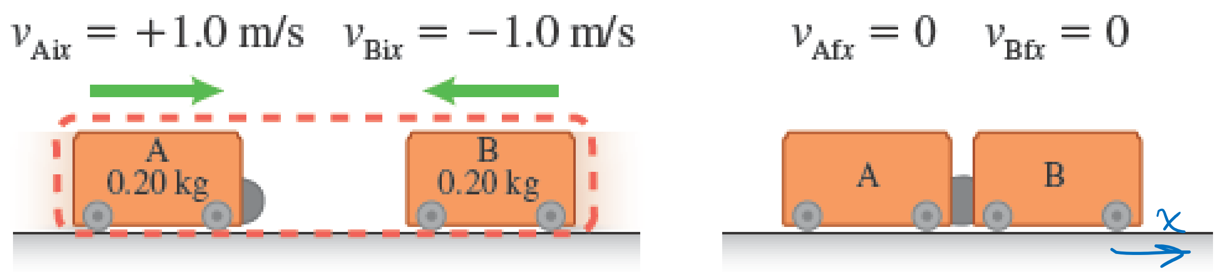


$p_{ix} = 0.4(+1.0) + 0$
$= +0.4$

$p_{fx} = 0.4(+0.4) + 0.2(+1.2)$
$= +0.16 + 0.24$
$= +0.4$

$\boxed{p_{ix} = p_{fx}}$

Ch.6 Observational Experiment 3 $p_x = mv_x$



$p_{ix} = 0.2(+1.0) + 0.2(-1.0)$
$= 0$

$p_{fx} = 0$

$p_{ix} = p_f$

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Momentum

- a property of moving things
- means inertia in motion
- more specifically, mass of an object multiplied by its velocity
- in equation form:

Momentum = mass × velocity

$\vec{p} = m\vec{v}$
or in components:
$p_x = m v_x$
$p_y = m v_y$

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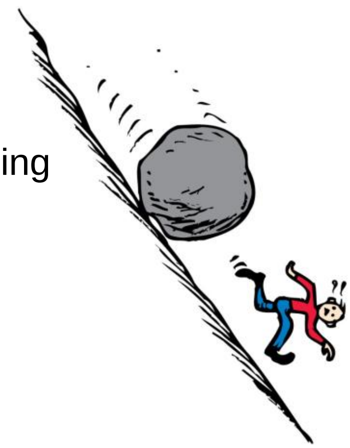
Momentum

Examples:

- A moving boulder has more momentum than a stone rolling at the same speed.
- A fast boulder has more momentum than a slow boulder.
- A boulder at rest has no momentum.



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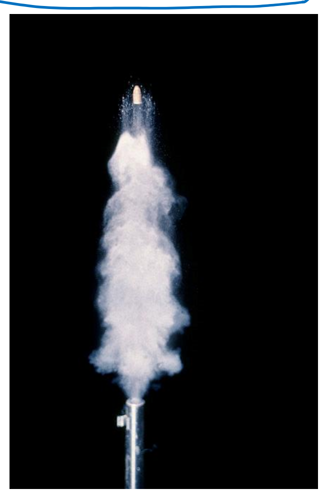
Examples

- A 1000 kg car travels west at 25 m/s. What is its momentum?

$m = 1000\ kg$

$\vec{v} = 25\ m/s$, West

$\boxed{\vec{p} = 25{,}000\ \frac{kg \cdot m}{s},\ \text{West}}$



- A 0.01 kg bullet is fired straight up, and leaves the gun with a muzzle speed of 1000 m/s. What is its momentum?

$m = 0.01\ kg$

$\vec{v} = 1000\ \frac{m}{s}$, up.

$\boxed{\vec{p} = 10\ \frac{kg \cdot m}{s},\ \text{up}}$

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Poll Question. Can you do the math?

A 10 kg cart is moving to the left at 2 m/s. Define positive as "towards the right", so its initial velocity is –2 m/s.
The cart suddenly stops. What is the change in momentum of the cart?

A. –20 kg m/s
B. –10 kg m/s
C. 0 kg m/s
D. 10 kg m/s
E. 20 kg m/s

$\xrightarrow{+x}$

$\Delta p_x = p_{fx} - p_{ix}$

Initial: $v_{ix} = -2\ m/s$

$p_{ix} = -20\ \frac{kg\, m}{s}$

Final: $v_{fx} = 0$ $p_{fx} = 0$

$\Delta p_x = 0 - (-20)$

$\Delta p_x = +20\ \frac{kg \cdot m}{s}$

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Chapter 6 big idea:
"Conservation of Momentum"

- A system of particles has a total momentum, $\vec{P}$
- If the system is isolated, meaning that there is no external net-force acting on the system, then:

$$\vec{P}_f = \vec{P}_i$$

- This means the momentum is "conserved"; it doesn't change over time.

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Last Time I asked

- When a ball is thrown up in the air and then falls back down, is its momentum conserved during freefall?
- Answer: NO!
- Whenever there is a net force on an object, its momentum is constantly changing.
- Conservation of Momentum happens on a system for which the external net forces are zero or are negligible compared to internal forces (such as during a collision)

Poll

Imagine you are trapped in a canoe in the middle of a still lake with no paddles. There is a large pile of heavy rocks in the canoe.

If you start throwing rocks, can you propel the canoe this way? And, **if** so, and you want to get to shore, which way should you throw the rocks?

A. No, you can't move the canoe significantly

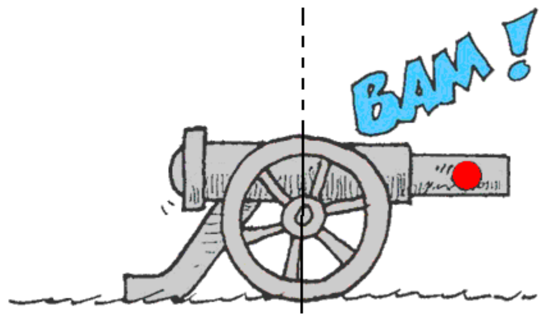
B. Yes, throw the rocks toward the shore

C. Yes, throw the rocks away from the shore.

[image downloaded Jan.16 2013 from http://campbellpost.wordpress.com/2012/01/26/canoe/]

Law of conservation of momentum:

In the absence of an external force, the momentum of a system remains unchanged.



- When a cannon is fired, the force on the cannonball inside the cannon barrel is equal and opposite to the force of the cannonball on the cannon.
- The cannonball gains momentum, while the cannon gains an equal amount of momentum in the opposite direction—the cannon recoils.

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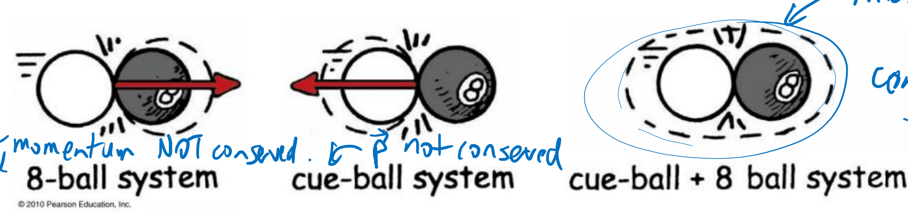
Conservation of Momentum

Examples:

- Internal molecular forces within a baseball come in pairs, cancel one another out, and have no effect on the momentum of the ball.
- Molecular forces within a baseball have no effect on its momentum.
- Pushing against a car's dashboard has no effect on its momentum.



momentum NOT conserved. $\vec{p}$ not conserved

momentum is conserved $\vec{p}_f = \vec{p}_i$

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$p_{i\,system} = 0$

- Two ice skaters, Paula and Ricardo, push off from each other. They were both initially at rest. Ricardo has a greater mass than Paula. Which skater has the greater magnitude of momentum after the push-off?

A. Ricardo

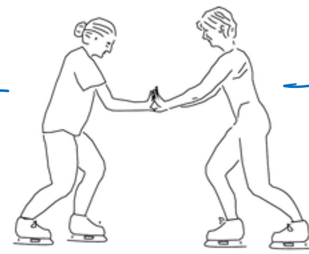
B. Paula

C. neither

R P

p_{fR} −

p_{fP} +



$p_{fR} + p_{fP} = 0$

$p_{fR} = -p_{fP}$

$|p_{fR}| = |p_{fP}|$

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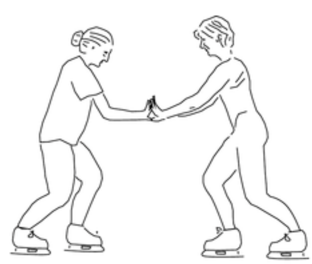
- Two ice skaters, Paula and Ricardo, push off from each other. They were both initially at rest. Ricardo has a greater mass than Paula. Which skater has the greater speed after the push-off?

A. Ricardo

B. Paula

C. neither



$v_{pf} = \frac{p_{pf}}{m_p}$

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Collisions

- For most collisions, the forces involved in the collision itself are much greater than any external forces, such as friction.
- Therefore, the net momentum before collision equals net momentum after collision.
- in equation form:

$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

[image downloaded Jan.21 2013 from http://findcheaperinsurance.ca/blog/7-common-car-accident-causes-part-2/]

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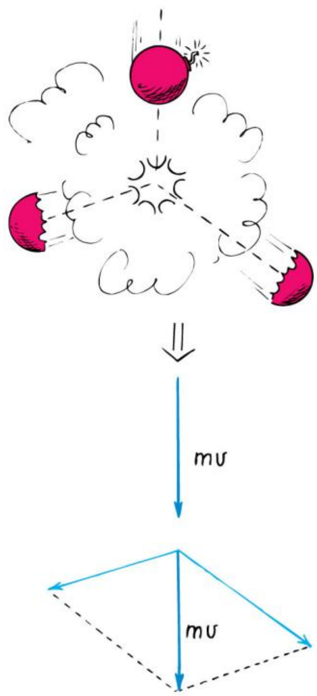
Explosions

Another example:

A firecracker exploding; the total momentum of the pieces after the explosion can be added vectorially to get the initial momentum of the firecracker before it exploded.



[animated gif downloaded Jan.21 2013 from http://bestanimations.com/Holidays/Fireworks/Fireworks.html]

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Before Class 17 on Wednesday

- Please read:
- 6.3 Impulse
- 6.4 The Impulse-Momentum Principle

- For the next 30 minutes I will be in the PHY131 Help Centre
- Zoom Meeting ID: 938 0964 2256
- Passcode: 723874

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